Evolution of Nonlinear Internal Waves in China Seas

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LONG-TERM GOAL

To study nonlinear ocean internal wave processes in the East and South China Seas, and Yellow Sea by using satellite synthetic aperture radar (SAR) imagery, in-situ data, and numerical models.

SCIENTIFIC OBJECTIVES

To Understand the environmental effects (e.g. bottom topography, shoaling, mixing, and current/shear) on nonlinear internal wave generation, evolution, and dissipation. Of particular interest is the generation of elevation internal waves by upwelling northeast of Taiwan caused by the intrusion of Kuroshio on the continental shelf. The challenge is to collect in-situ measurements simultaneous with satellite coverage and to synthesize all data by numerical models.

APPROACH

Synthetic Aperture Radar (SAR) images from ERS-1/2 and RADARSAT have been used to study the characteristics of internal waves northeast and south of Taiwan in the East China Sea, South China Sea, and in the Yellow Sea in conjunction with moorings and field measurements. The numerical simulations of internal wave evolution on the continental shelf have been performed and compare with SAR observations, especially for the evolution of nonlinear waves and the disintegration of solitons into wave packets. A parametric study for various environmental conditions to assess the nonlinear effects such as bottom topography (across critical depth), shoaling, and dissipation has been conducted. The generation and evolution of internal waves, and wave-wave interaction will be studied using satellite data in conjunction with in-situ data from the field experiments. All data will be synthesized/integrated by using numerical models.

WORK COMPLETED

Based on the SAR images and hydrographic data, internal waves of elevation have been identified in shallow water due to a thicker mixed layer as compared with the bottom layer on the continental shelf (Liang et al., 1995). The generation mechanisms including the influences of the tide and the Kuroshio intrusion across the continental shelf for the formations of both elevation and depression internal waves under various ocean conditions have been investigated (Hsu et al., 1999). The effects of water depth on the evolution of solitons and wave packets are modeled by nonlinear Kortweg-deVries (KdV) type equation and linked to satellite image observations. A parametric study for various environmental conditions has been carried out by numerical simulations to demonstrate and to assess the nonlinear effects such as bottom topography, shoaling (across critical depth), dissipation/mixing, and wave-wave

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interaction on internal wave evolution..

In the South China Sea, both depression and elevation waves were observed in the SAR images during the summer and spring seasons at the same location, respectively (Liu et al., 1998). The internal wave packets with more than 15 solitons were observed and measured by the ERS-1 SAR and the thermistor chain from a research ship in the Yellow Sea. Based on the SAR images, these many solitons may be caused by the wave-wave interaction (Hsu et al., 1998). The comparisons of the characteristics of the internal wave evolution in the US East coast water, in the East and South China Seas, and Yellow Sea have been identified. Recently, the internal wave distribution maps have been compiled from more than three hundreds of ERS-1/2, RADARSAT and Space Shuttle SAR images in the East and South China Seas and Yellow Sea from 1993 to 1998 by Hsu et al. (1999).

RESULTS

The Kuroshio moving north from Philippine Basin branches out near the south tip of Taiwan. A part of the Kuroshio intrudes into the South China Sea through the Bashi Channel and the Luzon Strait. The internal tides and internal waves have been generated by the shallow ridges in the Luzon Strait. Surface signature pattern of huge internal soliton packets has been observed in the ERS-1 SAR image. The crest of soliton is more than 200 km long and each packet contains more than ten rank-ordered solitons with a packet width of 25 km. These are the biggest internal waves that have been observed in this area. The internal wave amplitude is larger than 100 m with surface rips of 1 km wide, based on the observations and CTD casts from Taiwan's research ship during their South China Sea expedition. These huge wave packets propagate and evolve into the deep South China Sea and will reach the continental shelf of southern China.

In the northeast of Taiwan, the generation of both depression and elevation internal waves by upwelling caused by Kuroshio intrusion on the shelf under different mixed layer conditions has been demonstrated by numerical simulations (Hsu et al., 1999). In the Yellow Sea, the interaction of nonlinear internal wave packets shows the merging of solitons to a larger single wave packet. The wave-wave interaction observed from the satellite has been studied to interpret the ship measurements from ONR shallow water acoustics experiment in August 1996. The internal wave distribution maps for the East and South China Sea and Yellow Sea based on more than 300 satellite images have been compiled and are the most recent and important information for future planning of internal wave related field tests (e.g. ONR shallow water acoustics experiment in year 2000) in these areas.

During the South China Sea Monsoon Experiment (SCSMEX) in 1998, we have collected many SAR images in almost real-time. Based on the RADARSAT ScanSAR images (500 km * 500 km) collected on April, 26 and May 4, 1998, huge internal solitons were observed near Dong-Sar Island with crest more than 200 km long and wave speed of 1.9 m/s. Most interesting process is the observation of elevation internal waves in shallow water (220 m) and depression waves on the shelf break (500 m depth) in the same SAR image (5/4/98). The effects of water depth on the evolution of solitons and wave packets have been modeled by KdV-type equation and linked to the satellite observations. For a case of depression waves in deep water, the solitons first disintegrate into dispersive wave trains and then evolve to a packet of elevation waves in the shallow water area after they pass through a "critical depth" of approximately equal layer thickness as demonstrated by numerical model (Liu et al., 1998). Based on the numerical simulations, the evolution time for conversion is about 20 hours, and the wave

propagation distance can be as far as 200 km which are consistent with the SAR observations. Based on CDT casts during SCSMEX, the mixed layer depth is about 100-150 m, which is also consistent with the prediction from SAR observation of elevation internal waves. Also, in the ScanSAR image near Dong-Sar Island, the westward propagating huge internal solitons are often encountered and broken by the coral reefs on the shelf. In some cases, the broken wave crests will re-merge after passing the island and interact with each other with a phase shift.

IMPACT/APPLICATION

It is clear that these internal wave observations at northeast of Taiwan in the East China Sea, in the South China Seas, and in the Yellow Sea provide a unique resource for addressing a wide range of processes (Liu et al., 1996). Among these the following may be included: the generation of elevation internal waves by upwelling due to the Kuroshio intrusion across the continental shelf (notheast of Taiwan); the generation of internal waves by current-island interaction (in the Yellow Sea), the evolution of nonlinear depression waves through the critical depth (in the South China Sea); the disintegration of solitons into internal wave packets; internal wave breaking and turbulent mixing on wave propagation; the shoaling effects of variable bottom topography on wave evolution; and internal wave-wave interaction. The inclusion of these physical processes is essential to improve quantitative understanding of the coastal dynamics. The effects of internal wave on acoustic propagation is a very important issue as demonstrated in the Yellow Sea Acoustic/Internal Wave Experiment carried out in August, 1996. Field data will be collected by routine survey of Taiwan’s research ships in the South China Sea after SCSMEX in 1998. The ONR Shallow Water Acoustic Experiment will be conducted in the East and South China Seas starting in year 2000. Six research ships with scientists from US and China will participate in this experiment. One of the major tasks is to study the effects of large-amplitude internal wave packets on the propagation of sound.

TRANSITIONS

We have collected many SAR images in the Yellow Sea to help the field test planning of an ONR-funded (Ocean Acoustics Program) study in the Yellow Sea in August 1996. Our internal wave evolution model has been used in a NRL/SSC study of internal wave effect on acoustic propagation. Recently, we have compiled the internal wave distribution maps from more than three hundreds of ERS-1/2, RADARSAT and Space Shuttle SAR images in the East and South China Seas and Yellow Sea from 1993 to 1998. We are getting more SAR images to compare with SCSMEX field test data and try to interpret test results by numerical simulations. The internal wave distribution maps for the East and South China Sea and Yellow Sea are the most recent and important information for future planning of internal wave related field tests such as ONR shallow water acoustics experiment in year 2000.

RELATED PROJECTS

Professor Ming-Kuang Hsu of National Taiwan Ocean University has collaborated with us to coordinate the field measurements of internal waves during Taiwan's KEEP-II experiment and to provide the required environmental and current measurements. He was sabbatical and visited NASA/GSFC for six month in 1998 to study internal waves. Regularly scheduled hydrographic surveys by Taiwan's research ships with CTD casts, thermistor chains, marine radar, acoustic echo sounder and

long-term direct current observations with four moored ADCP's will be conducted by Prof. Joe Wang of the Institute of Oceanography of the National Taiwan University in the South China Sea and Prof. M.-K. Hsu of the National Taiwan Ocean University in the East China Sea.

Dr. John Apel is working with me on the effects of internal wave on acoustic propagation in the Yellow Sea Experiment carried out in August, 1996 in conjunction with the ONR Ocean Acoustics Program. I have been also working with SCSMEX team and actively involved in the planning of ONR shallow water acoustics experiment in China Seas. Prof. Hsu and I have submitted a proposal to European Space Agency for EnviSAT SAR data to study internal waves in the South China Sea. These in-situ wave and current measurements will provide a check on SAR observations and an input for the numerical simulation of wave evolution on the continental shelf.

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